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Published in:
Proceedings of IAQVEC 2007

Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

THE EFFECT OF USING LOW-POLLUTING BUILDING MATERIALS ON VENTILATION REQUIREMENTS AND ENERGY USE IN BUILDINGS

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ABSTRACT

The main objective of the ongoing research project described in this paper was to study the potential for reducing energy used for ventilating buildings by using low-polluting building materials, without compromising the indoor air quality. To quantify this potential, the exposure-response relationships, i.e. the relationships between ventilation rate and perceived indoor air quality, were established for rooms furnished with different categories of polluting materials and the simulations of energy used for ventilation were carried out. The exposure-response relationships were based on a summary of data reported in the literature on exposure-response relationships for materials tested in laboratory settings in small-scale glass chambers, and in full-scale in climate chambers, test rooms or normal offices. New experiments were also considered in which the effect of using low-polluting materials on perceived air quality was examined in test rooms ventilated with different outdoor air supply rates, low-polluting materials being selected in small glass chambers. The results suggest that the exposure-response relationships vary between different building materials and that the perceived air quality can be improved considerably when polluting building materials are substituted with materials that pollute less. The preliminary energy simulations indicate that selecting low-polluting materials will result in considerable energy savings as a result of reducing the ventilation rates required to achieve acceptable indoor air quality.

KEYWORDS

Building materials; Perceived air quality; Ventilation; Energy

INTRODUCTION

There is a need to reduce energy consumption worldwide. One initiative to reach this goal is the EU Directive 2002/91/EC Energy Performance of Buildings (2002) that makes it obligatory to reduce energy consumption in buildings while taking into account the indoor environment. For most buildings this can only be achieved if the energy used for ventilation is also reduced, because it constitutes about 20-30% of the total energy consumed in buildings today. This, however, may lead to reduced ventilation rates and increased levels of air pollution from buildings, people and their activities, and thus to poorer indoor air quality, which contradicts the requirements of the EU Directive. The obvious solution for these apparently opposing requirements would be to reduce the pollution sources indoors. The main objective of this ongoing research project is to quantify to what extent the use of low-polluting building materials would reduce the energy used for the ventilation of buildings, without compromising indoor air quality as it is perceived by humans and not as it is defined by the concentration of air pollutants measured using chemical methods. This is achieved by summarizing the existing data on the effects of emissions from building materials on perceived air quality, by carrying out experiments in which the effects of using low-polluting building materials on the perceived air quality are examined and related to ventilation requirements, and by performing energy simulations examining the extent to which reducing ventilation rates, as a consequence of using low-polluting building materials, will affect energy use. The present paper summarizes the current status of the project.

THE EFFECTS OF USING LOW-POLLUTING MATERIALS ON VENTILATION

Several studies have previously investigated the effects of pollution emitted by building materials on indoor air quality as it is perceived by people, and related these effects to ventilation requirements.

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These data were summarized and systematized in the present project (Knudsen et al. 2006). For that purpose, peer-reviewed journals and proceedings of major conferences were searched for papers reporting the relationships between ventilation rate and perceived quality of air polluted by building materials. Studies reporting the measurements of perceived quality of air polluted by building materials in ventilated small-scale chambers and in full-scale climate chambers, test rooms or in actual buildings were included. Only papers that reported measurements of perceived air quality made by an untrained panel of subjects using the acceptability scale shown in Figure 1 were selected. To examine the effect of ventilation on the perceived air quality when different building materials are selected, the exposure-response relationships between the acceptability of air quality and the dilution achieved by changing ventilation were created by log-linear regression (Cain and Moskowitz 1974, Knudsen et al. 1998) using original data reported in the papers selected in the summary. The scientific literature included in the summary comprised papers published since 1988.

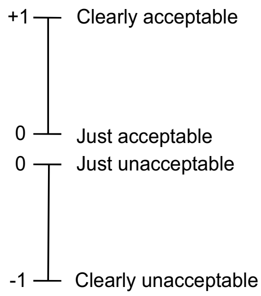

Figure 1. Scale used for assessing the perceived air quality (Wargocki 2004). The assessments are normally completed in the following context: "Imagine that during your work you would be exposed to this air". The coding of the scale (-1 to +1) is not presented to subjects during assessments but is used during analysis of data

Ten studies were included in the summary. Five studies were made in small-scale conditions with only facial exposure, i.e. the air was presented for evaluation through a diffuser and the samples of materials were placed in small glass chambers (Knudsen et al. 1998, Jørgensen et al. 1997, Haghighat et al. 2001, Wargocki et al. 2002, Sakr et al. 2003). Five studies were carried out in full-scale conditions with whole-body exposure, i.e. the assessments were made upon entering a test room, a climate chamber or an office in which samples of materials were placed (Wargocki et al. 2000, 2002, Knudsen et al. 2002, Skorek et al. 2004, Kolarik and Wargocki 2005). During both small-scale and full-scale evaluations subjects did not see the material samples. Detailed results of the summary are reported elsewhere (Knudsen et al. 2006). Some of them are illustrated in Figure 2 for single materials tested in small-scale experiments and in Figure 3 for both single materials and a combination of materials tested in full-scale experiments. The results show that the effect of changing the ventilation rate on the perceived quality of air polluted by different building materials can vary considerably. There are thus relatively large differences in the ventilation requirements needed to obtain a certain level of perceived air quality for emissions from different building products. There could be a number of factors causing the observed differences. They may for example include:
(i) the type of pollution source;
(ii) psychological factors such as context in which assessments are made (in laboratory vs. in real buildings);
(iii) expectations and previous experience with odours;
(iv) the information given concerning the pollution sources before assessments;
(v) physiological factors such as more or less adaptation to air pollution
(vi) perception of complex odour mixtures from e.g. combinations of building products;
(vii) chemical/physical factors, e.g. how products interact when air pollution is adsorbed and/or desorbed on material surfaces; and
(viii) reactive chemistry, e.g. when odorous secondary emissions are formed in reactions with for example ozone.
These factors should be taken into account when investigating the effects of using low-polluting materials on perceived air quality and ventilation requirements.

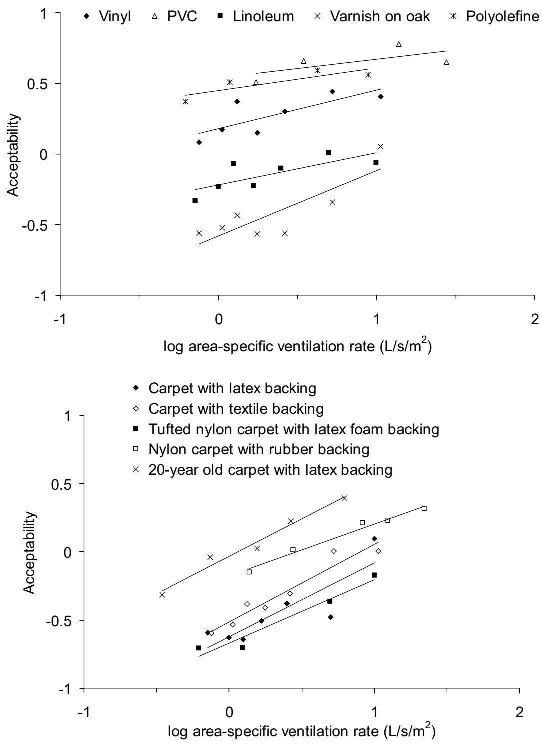

Figure 2. Exposure-response relationships for different hard-floor coverings (top) and carpets (bottom), created based on the assessments made in small-scale tests (Knudsen et al. 2006)

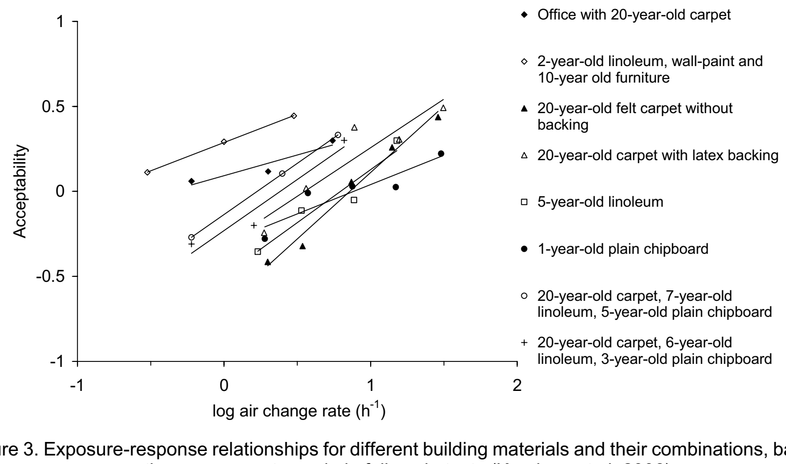

Figure 3. Exposure-response relationships for different building materials and their combinations, based on the assessments made in full-scale tests (Knudsen et al. 2006)

The summary showed in addition that there is a lack of systematic experiments in which building materials are first ranked according to their pollution strength, e.g. by using methods applied in labelling schemes (Witterseh 2002); the effect on the indoor air quality of using these materials in real rooms is then examined. Experiments were carried out to fill this gap (Wargocki et al. 2007). In these experiments a sensory panel assessed the air quality in full-scale test rooms ventilated with three different outdoor air supply rates and polluted by nine combinations of typical building materials including wall, floor and ceiling materials; the materials ranged from high- to low-polluting, and were ranked in this range using sensory assessments of air quality in small-scale glass chambers where they were tested individually. The relationships between the perceived air quality and ventilation rate were examined for different combinations of materials to assess the impact of using low-polluting materials and/or increasing the ventilation rate on the perceived air quality. The nine different building materials were selected using the results of preliminary experiments in which 20 building materials were screened individually in small-scale glass chambers, following the principles of the Nordtest methods (Nordtest 1990, 1998). The 20 materials were selected on the basis of the results obtained from the literature summary described above. The results show that the selection of the materials (tested individually in glass chambers and used in the combinations examined in the test rooms) turned out well, because both high- and low-polluting materials were included (Figure 4).

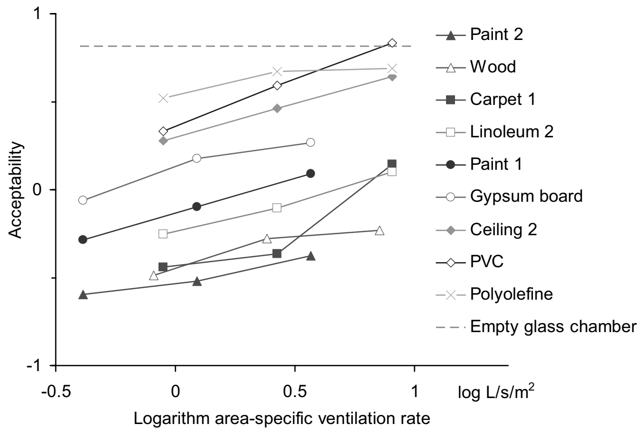

Figure 4. Acceptability of air quality as a function of the area-specific ventilation rate in small glass chambers containing the individual building materials that were examined in combinations in test rooms (Wargocki et al. 2007)

The materials tested individually in small-scale glass chambers were examined in combinations in the tests rooms. Figure 5 gives an example of the results obtained in test rooms. It shows that the air quality improved when the high-polluting paint on gypsum board (Paint 2) was substituted with lower-polluting paint on gypsum board (Paint 1) or unpainted gypsum board (Gypsum board). The improvement was greater than that achieved by increasing the outdoor air supply rate in a realistic range: a sevenfold increase of the outdoor air supply rate improved acceptability of quality of air polluted by a combination of materials including plastic-coated gypsum ceiling (Ceiling 2), polyolefine flooring (Polyolefine) and paint on gypsum board (Paint 1) less than substituting Paint 1 in this combination with lower-polluting gypsum board (Gypsum board). Similar results were obtained for nearly all other substitutions with the lower polluting building materials examined (Wargocki et al. 2007). The results show in addition that the decision as to which materials to substitute with low-polluting alternatives, should be based on ranking of materials, depending on their pollution strength; the highest polluting materials should be substituted first. This is illustrated in Figure 6 showing that substituting high-polluting untreated wood parquets (Wood) with lower-polluting linoleum flooring (Linoleum 2) or polyolefine flooring (Polyolefine) did not improve the assessments of acceptability of air quality when combinations of materials included high-polluting paint on gypsum board (Paint 2). The results imply also that some materials may clean the air. This is shown in Figure 5 where the acceptability of quality of air polluted by plastic-coated gypsum ceiling (Ceiling 2), polyolefine flooring (Polyolefine) and gypsum board (Gypsum board) is similar to the acceptability of air in the empty test room, probably due to adsorption on Gypsum board which is known to be a strong sink (Sakr et al. 2006).

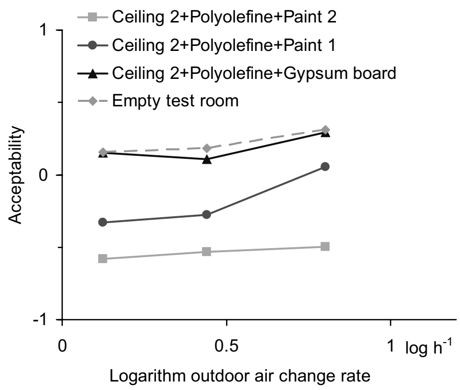

Figure 5. The effect of substituting high-polluting wall materials with lower-polluting materials on the air quality in the tests rooms (Wargocki et al. 2007)

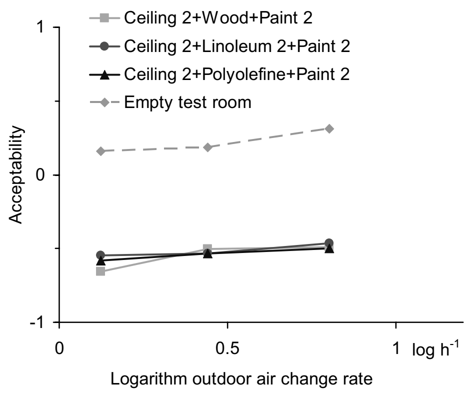

Figure 6. The effect of substituting high-polluting floor materials with lower-polluting materials on the acceptability of air quality in the tests rooms (Wargocki et al. 2007)

The results of these experiments confirm thus that reducing pollution sources by selecting lower-polluting building materials, ranked by means of sensory assessments made in small-scale glass chambers, improves the perceived air quality in full-scale rooms where these materials are used. However, indoor air is polluted not only by building materials. It is normally polluted also by human bioeffluents. The perception of the quality of air polluted by human bioeffluents is well described (Cain et al. 1983, Fanger and Berg-Munch, 1983, Iwashita et al. 1990) because the relationship between ventilation rate and perceived air quality (when bioeffluents are the main source of pollution) has been traditionally used to estimate ventilation requirements in buildings. These data cannot, however, be directly compared with the results obtained in the experiments described above. The reason is the difference in measuring scales used during assessments of the air quality: the air polluted by bioeffluents was assessed using a dichotomous (yes/no) acceptability scale, while the air polluted by building materials described above was assessed using a continuous acceptability scale. In future, it is important to investigate how the presence of bioeffluents in rooms with otherwise low-polluting building materials will influence the perceived air quality, and consequently ventilation requirements.

THE EFFECTS OF USING LOW-POLLUTING MATERIALS ON ENERGY

It is important to examine not only the effect of using low-polluting materials on ventilation requirements in buildings but, in addition, to discount this effect in energy terms. This part of the project is still in progress but the preliminary results and an approach are presented here.

Simulation of annual energy use in a two-person single office (floor area 21 m^2, volume 52.5 m^3) has been carried out using BSIM (Wiitchen et al. 2005). The office was assumed to have two different orientations (windows facing south or north) and three different methods of reducing heat loads: solar shading, cooling the air supplied to the office by the HVAC system and night cooling. The condition without systems used to reduce heat loads was simulated as well. The office was assumed to be ventilated with a mechanical ventilation system. In the simulations presented here two ventilation rates were analysed: 6 L/s and 117 L/s. 6 L/s per person was estimated as a minimum ventilation rate required for acceptable indoor air quality with two persons in the office (3 L/s per person), based on the assessments made by adapted persons (occupants) according to ASHRAE Standard 62 (ASHRAE 2007). 117 L/s was estimated as a maximum ventilation rate corresponding to 8 h^{-1}, which can be supplied with the available air terminals into the office without causing discomfort due to draught.

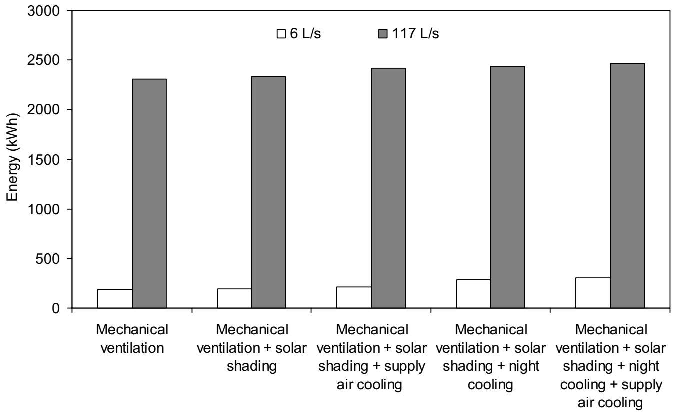

Figure 7. The results of simulation of energy use in an office ventilated with 6 and 117 L/s when different methods for reducing heat gains are used

The results of preliminary simulations for the office with south orientation are presented in Figure 7. They show that reducing the outdoor air supply rate to the minimum required by ASHRAE Standard 62 (ASHRAE 2007) will reduce to a large extent the energy used for conditioning and transporting the air (the energy presented is a sum of energy for operation of a fan (electrical energy multiplied by factor 2.5), heating and cooling). The results of simulation show, in addition, that at a ventilation rate of 6 L/s the thermal environment cannot be controlled, even when different methods of reducing heat loads are applied, either separately or simultaneously. Indoor temperatures, even in winter, were >25°C and in summer often >30°C. The aim now is to identify the extent to which the ventilation rate can be reduced without compromising the thermal environment. Simulations for the office with north orientation are in progress as well. All results from simulations will be eventually linked to the results showing how much the ventilation can be reduced when low-polluting materials are selected.

CONCLUSIONS

- Data were summarized reporting on the relationships between ventilation rate and the perceived air quality when building materials are main pollution sources and show that these relationships vary for different building materials.
- Substituting building materials with materials shown in small-scale chamber tests to be lower polluting improved the perceived air quality in full-scale test rooms but only when the highest polluting material was substituted with a lower polluting material.
- The improvement of the perceived air quality was greater than the improvement obtained by

increasing the outdoor air supply rate within a range that was realistic for indoor settings.

- Preliminary simulations of the operation of HVAC systems show that reducing ventilation requirements when low-polluting materials are selected will benefit energy savings. However, attention should be paid to the extent to which ventilation can be reduced without compromising the indoor climate, especially conditions required for thermal comfort.

ACKNOWLEDGEMENTS

The work was supported by the Danish Energy Agency through an EFP-05 project "Reduced energy use in buildings through selection of low-emitting building materials and furniture", contract #33031-0048. The authors wish to thank Jana Vondruskova and Pawel Zuczek who acted as research assistants in the experiments described and reported them in their M.Sc. thesis. Thanks are due to Kjeld Johnsen from SBi for assistance and help during energy simulations.

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